MECHANISTIC MODELS OF LIGHT-LIMITED AND LIGHT-SATURATED RATES OF PHOTOSYNTHESIS

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LONG-TERM GOALS

My long-term goals are to understand the causes of and mechanisms responsible for variability in phytoplankton abundance, primary production, and species composition.

OBJECTIVES

The objectives of this project are to develop mechanistic models for rates of primary production based on phytoplankton photosynthetic absorption coefficients and concentrations of the rate-limiting enzyme ribulose-1,5-bisphosphate carboxylase (Rubisco) that catalyzes carbon fixation. This work is supported by ONR Biological Oceanography and Ocean Optics.

APPROACH

Photosynthesis is a term that encompasses multiple reactions starting with the absorption of photons and ending with the ribulose-1,5-bisphosphate carboxylase-catylzed reduction of carbon dioxide and incorporation into a simple sugar. The process is usually summarized as two main processes: 1) the light-mediated reactions and 2) the enzymatic reactions. The photosynthesis vs. irradiance (P vs. E) functional response has two corresponding components: 1) a light-limited region at lower irradiances for which photosynthetic rate is a function of the photosynthetic absorption coefficient, irradiance, and the quantum yield and 2) a light-saturated region at higher irradiances for which photosynthetic rate in the ocean is primarily limited by the functional concentration of the enzyme ribulose-1,5-bisphosphate carboxylase. Our approach is that the most appropriate mechanistic model of primary production is a normalization of light-limited rates of photosynthesis to photosynthetic absorption coefficients and light-saturated rates to ribulose-1,5-bisphosphate carboxylase activities.

WORK COMPLETED

We measured the rate of light-saturated photosynthesis as a function of the activity of the key photosynthetic enzyme ribulose-1,5-bisphosphate carboxylase (Rubisco) for a

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number of phytoplankton species cultured in the laboratory. The activity assay provides a rate of carbon dioxide reduction that reflects the product of the enzyme concentration and its specific rate. The Rubisco activities were determined at the same temperature as the photosynthetic measurements, and hence did not need to be temperature-corrected for in situ carboxylation rates. For dinoflagellates, we found that instantaneous freezing of the filtered samples in liquid nitrogen was essential for retention of enzyme activity. Activities were measured on thawed samples. A strong correlation between light-saturated photosynthetic rate and Rubisco activity was observed for the laboratory measurements. We are currently evaluating this method for field phytoplankton in Puget Sound and coastal Oregon waters; preliminary results are similar to those from laboratory samples.

A method for determining the phytoplankton photosynthetic absorption coefficient in field samples was used, based on spectral fluorescence excitation/emission and spectrophotometric methods (Culver et al., 1994; Culver, 1996; Culver and Perry, submitted). This approach allowed us to determine the true photosynthetic absorption coefficients and actual photosynthetic quantum yields. Photosynthetic and photoprotective absorption coefficients were measured at diverse hydrographic locations in Puget Sound, Washington. The ratio of photoprotective to photosynthetic absorption coefficients was found to be a function of ambient irradiance in stratified waters but was not a function of ambient irradiance in mixing environments (Culver and Perry, submitted).

RESULTS

Our results show that Rubisco activity can be used to estimate light-saturated rates of photosynthesis. An important advantage of this method is that it can replace the need for ship-board incubations with radio-labeled carbon; samples can be filtered at sea immediately after collection and stored in liquid nitrogen for shore-based laboratory analysis. Our results also help to explain some of the observed variability in values of P_{max} (light-saturated photosynthesis) normalized to chlorophyll *a* concentration.

The use of a spectral photosynthetic absorption coefficient is an advance for studying and modeling light-limited rates of photosynthesis. Historically, photosynthetic rate has been normalized to chlorophyll *a* concentration. Chlorophyll *a* is easy to measure and for a long time has been used as a proxy for the absorption of photons by all photosynthetic pigments. However, the absolute magnitude of the chlorophyll *a*-specific spectral absorption coefficient changes with accessory pigment concentration, species composition, cell size, and previous irradiance history. The relative spectral absorption coefficient also changes with the ratio of different accessory light-harvesting pigments. As a consequence, it is difficult to accurately determine the spectral photosynthetic absorption coefficient from chlorophyll *a* concentration alone.

Recently it has been possible to measure the photosynthetic absorption coefficient directly, as a consequence of development of a spectral excitation/emission fluorescence method (Sakshaug, et al., 1991; Culver et al., 1994; Sosik and Mitchell, 1995). The

underlying concept is that only pigments involved in photosynthesis can stimulate chlorophyll *a* fluorescence; hence, it is possible to derive the absorption coefficients of photosynthetic pigments from fluorescent excitation/emission spectra (cf. Neori et al., 1986). The absorption coefficient of the photoprotective pigments can also be determined by difference between the total phytoplankton absorption coefficient and the photosynthetic absorption coefficient.

IMPACT

By modeling photosynthesis in context of the underlying mechanistic parameters (i.e., photosynthetic spectral absorption coefficient and Rubisco activity), we should improve our understanding of why and how photosynthetic rates change. These rates directly affect why and how upper ocean optical properties change.

By explicitly separating the two components of the phytoplankton absorption coefficient (the photosynthetic and the photoprotective components), it will be possible to constrain and predict the spectral variance in the total phytoplankton absorption coefficient.

TRANSITIONS

A knowledge of the dynamics of the two components of the phytoplankton absorption coefficient has important implications for hyperspectral remote sensing.

RELATED PROJECTS

The ASSERT awar # N00014-97-1-0645 will support graduate student research in cooperation with the parent grant to the PI.

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